REVIEW, **50**:313–14. Doctor Wüst accepts the values for precipitation, run-off and evaporation given by Fritzsche,[2] for the region between 60° N. lat. and 40° S. lat. and supplementing these by assigning values for the regions poleward he arrives at the conclusion that the annual evaporation from the land amounts to 75,000 cu. km. per year or 21,989 cu. km. less than Brückner's determination of an earlier date.

Practically all of the investigators have followed Murray in considering the total quantity of evaporation from land areas as the difference between the total rainfall thereon and the amount of water discharged by the rivers into the oceans.

Each investigator places the total precipitation over the entire earth as equal to the total evaporation. I introduce at this time a small comparative table from Wüst (loc. cit.) giving the results reached by the several students of the problem.

Different determinations of the hydrology of the earth

[Amounts in 1,000 km.³/year]

	Precipitation			Evaporation		
	Fritzsche-Brückner	Schmidt-Fritzsche	Wüst-Fritzsche	Fritzsche-Brückner	Schmidt-Fritzsche	Wüst-Fritzsche
Ocean	353.4	242.4	267.1	384.0	273.0	304.2
Land	111.9	111.9	112.1	81.3	81.3	75.0
Earth	465.3	354.3	379.2	465.3	354.3	379.2

From the above table it may be seen that in general the results of the six investigators as paired by Wüst are mostly in fair agreement; in some cases, however, the disagreements are rather marked, for example, Fritzsche-Brückner estimate the total precipitation of the earth as 465,300 cu. km. while Schmidt-Fritzsche place it at 354,300 cu. km. or 111,000 cu. km. less. Wüst-Fritzsche estimate the total evaporation at 86,100 cu. km. less than Brückner and Fritzsche.

Doctor Wüst is of opinion based on the results of Bigelow's work that it is necessary to apply a reduction factor of 0.82 to Brückner's results making the total oceanic evaporation as given by him 79,800 cu. km. too great. Accepting this criticism the total oceanic evaporation quoted by Zon [3] from Brückner is about 19,000 cu. miles too great. (79,192 cu. km.)

The investigators subsequent to Murray followed his lead in neglecting the amount of water annually devoted to replenishing the water that is very deep in the earth's crust such as artesian flow and that derived from deep wells, 3,000 to 4,000 feet in depth. It is true, of course, that approximate equilibrium in the free water content of the earth's crust has been reached many ages ago; nevertheless it would seem on first thought that very considerable draughts on that supply are made annually and that these amounts must be replenished by rainfall.

Very few worth-while statistics of the draft that is made on the deep earth water supply are available, but using what few can be found, computation shows that the total amount when compared with the total rainfall of the globe may be neglected. At best the water so used is lumped with total evaporation and serves to make that quantity slightly larger than it should be.

I also question the accuracy of the item given by Brückner and quoted by Zon (loc. cit.), viz, "Amount of ocean vapor carried to the land (net)" on the ground that neither the amount of water vapor carried by the atmosphere where it impinges on the land nor the amount of air exchange between land and sea is or can be even approximately known. The best that can be said is that on the average of a number of years the amount of exchange of air is substantially the same.

The unfortunate thing about the statement above quoted and others of like character which occasionally come from persons of high standing in their chosen professions is that the lay reader frequently does not and can not distinguish between the sound and the unsound when matters concerning the physical properties of the atmosphere are concerned.

Another statement by Brückner which in the original is quite correct, but by the suppression of a modifying clause is erroneously interpreted, is the emphasis placed on the importance of land masses as furnishing a supply of water vapor that is later condensed and falls as rain or snow.

I quote a translation of his words and have italicized those most generally omitted in quotations.

> Not ineffective is the rôle which the land surface plays in the circulation; on a mighty scale it adds to the moisture content of the air; nearly two-thirds of the rain falling on land comes from the masses of vapor furnished by itself and is thus of continental origin. *To be sure, the ocean is the source of these masses of vapor;* it furnishes a certain amount of water which repeatedly changes position over the land, here rather rapidly, there more slowly, and thus enters many times into the phenomenon of precipitation. (Geographische Zeitschrift, Vol. VI, p. 96.)

In discussing this subject with my colleague, Dr. W. J. Humphreys, he reverted to the fact that some years ago, to be precise, in 1914, he had drawn up a concise statement of the relations between world evaporation, precipitation, and run-off. Doctor Humphreys has kindly consented to the publication of this statement. See the succeeding article.

[1] Die Verdunstung auf dem Meere. Veröff. d. Inst. f. Meerskunde, N. F. Reihe A Heft 6 1920 (885).

[2] Niederschlag, Abfluss und Verdunstung an freien wasserflächen ein Beitrag zum Wärmehaushalt des Weltmeeres und zum wasser haushalt der Erde. Ann. d. Hydrog. usw. 1915.

[3] Zon, Raphael, Final Report National Waterways Commission, 1912. (Zon's article in this report was recently reprinted.)

SOME RELATIONS BETWEEN EVAPORATION, PRECIPITATION, AND RUN-OFF

By W. J. HUMPHREYS

Many efforts have been made to find important relations between evaporation, precipitation, and run-off, but while such relations can be found it nearly always happens that it is impossible to deduce from them the value of any one of the quantities in terms of measurable values of the others. The restricted range and application of these relations will be clear from the following:

(1) *For the world as a whole.*—Evaporation = Precipitation.

(2) *For all land areas jointly.*—

Let P_o = precipitation coming from ocean evaporation.
P_L = precipitation coming from land evaporation.
$P = P_o + P_L$ = total precipitation over land.
R_s = surface run-off.
R_u = underground run-off.
R = total run-off.
E = total land evaporation.

Then $P_o = R$; $P_L = P - R = E$.

That is to say, the greater the precipitation on the land the larger the evaporation from it, unless the increase in run-off equals the increase in the precipitation, which we know in general it does not. This, however, does not prove that the precipitation is to any extent increased by the land evaporation—though there are good reasons for thinking that it is. If it does not increase land precipitation it must then increase ocean precipitation, for total evaporation from land and ocean must equal total world precipitation. But, as implied, it is preactically certain that, owing to vertical convection caused by surface heating and by mountain ranges, land evaporation increases land precipitation more than ocean precipitation.

(3) *For a restricted area—a given watershed, say.*—

Let V_i = amount of vapor brought by winds to the given region in a year.

V_o = amount of vapor carried by winds from the given region in a year.

p_1 = amount of precipitation from vapor V_i on the given region in a year.

p_2 = amount of precipitation from evaporation over the given region in a year.

$P = p_1 + p_2$, or total precipitation on the given region in a year.

R_s = surface run-off from the given region in a year.

R_u = underground run-off from the given region in a year.

$R = R_s + R_u$, or total run-off from the given region in a year.

E = evaporation from the given region in a year.

Then $V_i - V_o = R_s + R_u < p_1$, because some of the local precipitation is supplied by local evaporation, as in heat thunderstorms, for instance; $P - (R_s + R_u) = E > p_2$, since some of p_1 also is evaporated. These seem to be the only useful equations available between the terms given. In a closed basin where $R = 0$, $E = P$; in an open basin, $E = P - R$. Some measurements indicate that at places P may be several fold R. Say, $P = AR$, then $E = (A-1)R$. But P and R_s are measurable, and often the value of R_u can be approximated—seldom more, perhaps, than 1 per cent of R_s. Hence, a more or less accurate value of E is determinable.

In regard to a restricted area we can only say that the evaporation is a result of the precipitation—we can not say to what extent the local precipitation is a result of local evaporation.

It is obvious, however, that evaporation from vegetation and from the soil often is very great—the temperature of the air frequently is high (many degrees higher than over the ocean at the same latitude), the tree foliage is well up in the atmosphere, and finally the air is well mixed—more so than over the ocean. For all these reasons—high temperature, elevation of evaporation surfaces, and mixing of air—it seem certain that, when moist, land evaporation must be great and free. It is also obvious that this evaporation must increase leeward precipitation, but to what extent does not at present seem determinable.

That local evaporation increases leeward precipitation seems to be the logical explanation, at least in part, of, among other things, the facts (*a*) that "all signs fail in dry weather"; (*b*) that "during wet weather it can rain without half trying"; and (*c*) that in the case of a rapid succession of rain storms passing over a semiarid region, each penetrates farther than its predecessor. Professor Henry has called my attention to examples of (*c*) on the Pacific coast of the United States.

PRECIPITATION, EVAPORATION, AND RUN-OFF

By W. J. HUMPHREYS

Dr. C. E. P. Brooks's timely and admirably conservative paper on the influence of forests on rainfall and run-off [1] appears to offer a possible means of determining relations between precipitation, evaporation, and run-off that after all may not be as reliable as it seems. This is not a criticism of his fine contribution to an intricate subject, but rather a reminder of an inherent difficulty that no one yet has managed to solve.

Let all quantity symbols refer to the average amount per second. Let P be the total precipitation per second, as specified, over the land; R, the run-off; and E, the evaporation; then

$$P = R + E$$

Some of E is reprecipitated on the land—call it P'; and some, x, is not. Hence

$$P = R + P' + x \tag{1}$$

and

$$P - P' = R + x$$

If V_{op} is the amount of on-shore vapor that is precipitated onto the land and V_o the amount of on-shore vapor that is not so precipitated; and, finally, if the total amount of water vapor coming to the land from the ocean is n times the amount leaving the land, then

$$V_{op} = R + x$$

$$V_o + V_{op} = n\ (V_o + x)$$

and

$$x = \frac{R}{n-1} - V_o$$

If n is 2, a reasonable assumption suggested by Brooks,

$$x = R - V_o;$$

but we have no means by which to determine V_o, hence x also is unknown. Brooks appears to assume that V_o is negligible and thus gets the relation

$$x = R.$$

On substituting this value of x in (1), it would seem that the precipitation on the land due to evaporation from the land is equal to the *total* precipitation thereon less twice the run-off; or, in symbols, that

$$P' = P - 2R.$$

Actually, though,

$$P' = P - \frac{n}{n-1}R + V_o$$

But, as stated above, V_o is unknown; therefore P' also is unknown. And the more significant the value of V_o the less reliable any estimate we may make of P'.

[1] Q. Jr. Roy. Meteorol. Soc., 54, 1, 1928.